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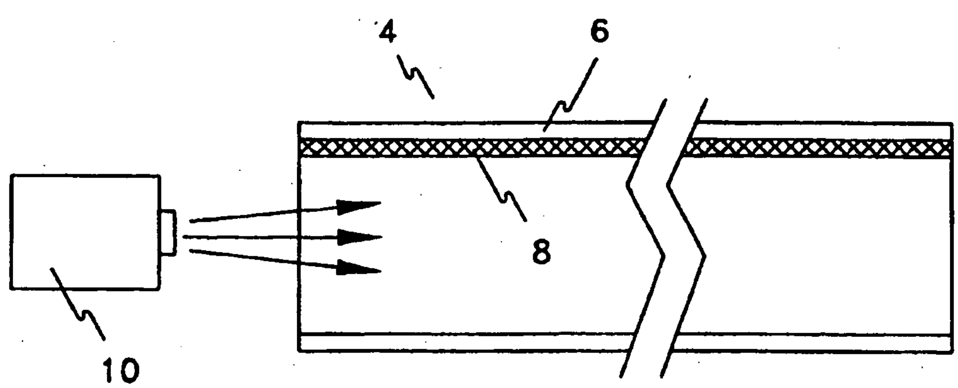
(54) Title: LIGHT PIPE UTILIZING PLASTIC SHEETS



(57) Abstract

A light pipe (4) includes a conduit (6) configured to receive light at one end and to distribute the light along its length. The conduit (6) includes a combination of specular and diffuse reflecting surfaces (8) arranged to pass a portion of the light down the light pipe (4) primarily with specular reflection and to emit a portion of the light out of the light pipe (4) primarily with diffuse reflection. The reflecting surfaces (8) are substantially parallel to a longitudinal axis of the light pipe (4). A plurality of conduit (8) may be used to control the light distribution characteristics of the light pipe (4). The conduit (6) may be made from inexpensive plastic sheet materials.

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LIGHT PIPE UTILIZING PLASTIC SHEETS

[0001] The invention described herein was made with Government support under Contracts Nos. DE-FC01-97EE23776 and DE-FC26-99FT40635 awarded by the Department of Energy. The U.S. Government has certain rights in this invention.

BACKGROUND

Field of the Invention

[0002] The present invention pertains to light pipes utilized for distribution of light from a light source. More particularly, the invention relates to a cost effective, efficient light pipe constructed from simple plastic sheet materials.

Related Art

[0003] Light pipes are conduits, typically made from optical material configured with surface to air interfaces providing total internal reflection (TIR), which distribute light from a light source over a large area. An example of such light pipes are described in U.S. Patent No, 4,260,220, entitled "Prism Light Guide having Surface which are in Octature," by Lorne A. Whitehead. The Minnesota Mining and Manufacturing Company (3M) produces a commercially available optical material called Optical Lighting Film (OLF) which is useful for constructing light pipes. An example of OLF is described in U.S. Patent No. 4,906,070.

[0004] One problem with conventional light pipes is that the optical material consists of micro-replicated prisms, perforated silvered plastic, or complex dielectric coatings on transparent surfaces. These approaches are relatively complex and costly.

[0005] Another problem with conventional light pipes is that some of the above-mentioned materials are also relatively inefficient in terms of distributing light from the source into the environment to be illuminated. For example, optical

materials providing TIR are designed to contain the light within the material. The trapped light undergoes numerous internal reflections before exiting. Each internal reflection involves a small amount of light loss and the cumulative effect can be substantial.

[0006] Light distribution uniformity can also be problematic for prismatic film. In order to utilize such material for distribution of light, irregularities are introduced into the material to allow light to escape. The process of light leakage is difficult to control and the light output of the distributed light over a large area varies considerably.

[0007] Publication No. EP 0 889 285 describes a light distributing tube which does not utilize prismatic film or TIR for light distribution. Instead, the light tube utilizes a geometrically complex three dimensional light redirecting structure inside the tube configured such that most of the light which strikes the redirecting structure exits the tube at the point of intersection between the light beam and the redirecting structure. A light source having a beam spread half angle of 4° or less is most preferred.

[0008] The applicants are also aware of a product called LITE HOSE which is made by SPACE CANNON ILLUMINATION, INC., in Fubine, Italy. To the best of applicants' knowledge, the LITE HOSE was first publicly demonstrated in Europe in the fall of 1998 and in the U.S. in the spring of 1999. The LITE HOSE consists of an extruded opalescent acrylic tube utilized in conjunction with light source having a 3° beam of light. The tubes range in size from 100 to 500 mm with a wall thickness ranging from 3 to 8 mm. The narrow beam of light is used to provide a long light throw through the tube. The primary application of the LITE HOSE is for theatrical lighting such as architectural outlining of buildings for dramatic effect.

SUMMARY

[0009] It is an object of the invention to provide a light pipe having a simple structure which efficiently distributes light over a large area. It is a another object of the invention to provide a light pipe with a high uniformity in the distribution of light.

[0010] According to one aspect of the invention, a light pipe includes a conduit configured to receive light at one end and to distribute the light along its length. The conduit utilizes a combination of specular and diffuse reflecting surfaces arranged to pass a portion of the light down the light pipe primarily with specular reflection and to emit a portion of the light out of the light pipe primarily with diffuse reflection. The reflecting surfaces are substantially parallel to a longitudinal axis of the light pipe. For example, the conduit may include a clear plastic tube with an interior surface which provides specular reflection and an opaque material disposed along the length of the tube and covering a portion of the perimeter of the tube, wherein the opaque material provides diffuse reflection. The opaque material may be disposed on an interior surface of the tube and provide a combination of specular reflection for shallow beam angles of light and diffuse reflection for higher beam angles of light. Alternatively, the opaque material may be disposed on an exterior surface of the tube, and the tube material and the opaque material together would provide a combination of specular reflection for shallow beam angles of light and diffuse reflection for higher beam angles of light. For example, the conduit may be made from extruded plastic or from plastic sheet material shaped to form a tube.

[0011] According to another aspect of the invention, a light pipe includes a plurality of conduits configured to receive light at one end and distribute the light along the length of the light pipe. The conduits are offset from each other by respective gaps and provide a combination of specular and diffuse reflecting

surfaces arranged to pass a portion of the light down the light pipe primarily with specular reflection and to emit a portion of the light out of the light pipe primarily with diffuse reflection. In some examples, the number of conduits vary along the length of the light pipe. In other examples, the length of at least one of the conduits is different from the length of another of the conduits. As noted above, each of the conduits may be made from either extruded plastic or plastic sheet material shaped to form a tube. In most examples, each of the conduits except an outermost conduit comprises clear plastic having a gloss finish on both its interior and exterior surfaces. In some examples, the outermost conduit comprises clear plastic having a gloss finish on its interior surface and a diffuse finish on its exterior surface. The light pipe may further include an opaque material disposed along the length of the outermost conduit and covering a portion of the perimeter of the outermost conduit. The opaque material may be disposed on an interior surface of the outermost conduit and provide a combination of specular reflection for shallow beam angles of light and diffuse reflection for higher beam angles of light. Alternatively, the opaque material may be disposed on an exterior surface of the outermost conduit, and the conduit material and the opaque material together provide a combination of specular reflection for shallow beam angles of light and diffuse reflection for higher beam angles of light.

[0012] According to yet another aspect of the invention, a light distribution system includes a light source providing a beam of light having a full beam angle of less than 30 degrees and a light pipe configured to receive the beam of light from the light source at one end and distribute the light along the length of the light pipe, the light pipe including a combination of specular and diffuse reflecting surfaces arranged to pass a portion of the light down the light pipe primarily with specular

reflection and to emit a portion of the light out of the light pipe primarily with diffuse reflection. Preferably, the light source provides a beam of light having a full beam angle of less than 20 degrees. For example, the light source may be sunlight. The light distribution system may further include an end cap covering an end of the light pipe distal to the light source, the end cap having a reflective surface positioned and shaped to redirect light back down the light pipe. In some examples, the light pipe comprises first and second substantially concentric conduits and the distribution system further includes a first mounting device adapted to support the first conduit, and a second mounting device adapted to support the second conduit and adapted to receive and support the first mounting device and first conduit within the second conduit. Preferably, the first and second mounting devices hold the first and second conduits in a non-contact relationship.

[0013] The foregoing objects, features, and advantages of the invention are achieved individually and in combination. The invention should not be construed as requiring two or more of the foregoing features unless expressly recited in the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] The foregoing and other objects, features, and advantages of the invention will be apparent from the following more particular description of the preferred examples as illustrated in the accompanying drawings in which like reference numerals generally refer to like elements throughout. The drawings are not necessarily to scale, emphasis instead being placed upon illustrating the principles of the invention.

[0015] Fig. 1 is a schematic illustration, in longitudinal cross section, of a transparent material exhibiting specular reflection.

[0016] Fig. 2 is a schematic illustration, in longitudinal cross section, of an opaque material exhibiting both specular and diffuse reflection.

[0017] Fig. 3 is a graph of reflectivity versus angle of incidence for an exemplary transparent material which exhibits specular reflection.

[0018] Fig. 4 is a schematic view, in longitudinal cross section, of a light pipe according to a first example of the invention.

[0019] Fig. 5 is a schematic diagram of a beam of light striking the diffuse reflecting material.

[0020] Fig. 6 is a schematic view, in longitudinal cross section, of a light pipe according a second example of the invention.

[0021] Fig. 7 is a schematic view, in cross section, of the light pipe illustrated in Fig. 6 taken along line 7-7.

[0022] Figs. 8-11 are schematic views of alternative structures for light pipes according to the second example of the invention.

[0023] Fig. 12 is a schematic diagram, in cross section, of an alternative construction of a light pipe according to the invention.

[0024] Fig. 13 is a schematic diagram of a beam of light striking the inside surface of the pipe.

[0025] Fig. 14 is a diagram of a light output pattern for a light pipe according to the invention utilizing a plastic sheet having a gloss finish on both sides.

[0026] Fig. 15 is a diagram of a light output pattern for a light pipe according to the invention utilizing a plastic sheet having a gloss finish on its interior side and a matte finish on its exterior side.

[0027] Fig. 16 is a schematic, cross sectional diagram of the light output from yet another example of a light pipe according to the invention.

[0028] Fig. 17 is a schematic, cross sectional view of a hemispherical shaped light pipe according to the invention.

[0029] Figs. 18-20 are schematic, cross sectional views of respective alternative shapes for light pipes according to the invention.

[0030] Fig. 21 is a schematic view of a first plastic sheet in a preliminary stage of preparation for forming a light pipe according to the present invention.

[0031] Fig. 22 is a schematic view of a second plastic sheet in a preliminary stage of preparation for forming a light pipe according to the present invention.

[0032] Fig. 23 is a cross sectional view of a first preferred configuration for a light pipe according to the invention.

[0033] Fig. 24 is a cross sectional view of a second preferred configuration for a light pipe according to the invention.

[0034] Figs. 25 and 26 are graphs comparing light output of the light pipe of the present invention with a conventional TIR light pipe.

[0035] Fig. 27 is a fragmented, perspective view of a first light pipe mounting device according to another aspect of the invention.

[0036] Fig. 28 is a fragmented, perspective view of a second light pipe mounting device according to the invention.

[0037] Fig. 29 is a schematic view of a light pipe coupling device according to another aspect of the invention.

[0038] Fig. 30 is cross sectional view of the light pipe coupling device taken along line 30-30 in Fig. 29.

[0039] Fig. 31 is a schematic, cross sectional view of a first light pipe end cap according to the present invention.

[0040] Fig. 32 is a schematic, cross sectional view of a second light pipe end cap according to the present invention.

[0041] Fig. 33 is a schematic view of a lens system suitable for use with the light pipe of the present invention.

[0042] Fig. 34 is a cross sectional view of the lens system taken along line 34-34 in Fig. 33.

DESCRIPTION

[0043] In the following description, for purposes of explanation and not limitation, specific details are set forth such as particular structures, interfaces, techniques, etc. in order to provide a thorough understanding of the present invention. However, it will be apparent to those skilled in the art having the benefit of the present specification that the present invention may be practiced in other examples that depart from these specific details. In other instances, detailed descriptions of well known structures, devices, and methods are omitted so as not to obscure the description of the invention with unnecessary detail.

[0044] TIR pipes can efficiently contain beams of up to 54-56° full beam angle. However, for the light to escape from the TIR pipe it must be scattered out of this angle. In direct contrast to TIR pipes, the light pipe of the present invention doesn't contain any of the light in the pipe material. The present invention utilizes a light source with a narrower beam angle. As discussed in connection with Figs. 5 and 12 below, except for the specular component (e.g. shallow, almost parallel beams) all other beams have a substantial likelihood of escaping the light pipe of the

present invention on each bounce. As noted above, TIR pipes use an extractor or irregularities in the OLF material intended to scatter a fraction of the incident light out of the containment cone angle. However, in contrast to the present invention, a significant fraction of the light remains within the cone angle, and must undergo multiple interactions with the extractor in order to be ejected from the pipe. TIR pipes therefore typically feature more bounces off the pipe per unit length, with an efficiency loss per bounce that is the same or greater than the present invention. The present invention is consequently more efficient, for a narrower beam angle light source, because of the relatively few bounces before the light escapes and lower losses per bounce.

[0045] In comparison with the light tube described in EP 0 889 285, the present invention provides much simpler construction. The present invention utilizes reflecting surfaces which are primarily substantially parallel to the longitudinal axis of the light pipe. In other words, the present invention does not use complex internal structures. Although the light tube described in the '285 publication avoids the use of prismatic film, the tube requires an admittedly geometrically complex, 3-dimensional light redirecting structure. This structure is a tapered extractor which extends along a substantial portion of the tube and subtends progressively greater areas of the tube cross-section at further distances from the light source. Although not explicitly stated, the principle of operation appears to utilize a long throw of light with a single reflection from the light redirecting structure to extract light from the tube. Consequently, the light pipe of the '285 publication requires a significantly narrower beam of light than that of the present invention. In any event, the '285 publication does not teach or suggest the principle of operation or simple structure of the present invention.

[0046] The present invention is based on the application of the following principles for light distribution. First, for shallow angles of incidence a glossy finished plastic provides a good specular reflective surface. Specifically, a glossy plastic exhibits glint reflection due to the high efficiency of Fresnel reflection at shallow angles. Second, for shallow angles of incidence many common opaque materials exhibit a combination of specular and diffuse reflection. According to the present invention, these principles are combined to provide a light fixture which is low cost, efficient, and uniformly distributes light from a suitably bright light source.

[0047] Fig. 1 is a schematic illustration, in longitudinal cross section, of a transparent material exhibiting specular reflection. A beam of light B_1 strikes the material 1 with an angle of incidence θ_1. A portion of the beam B_S is specularly reflected and a portion of the beam B_T is transmitted (the diagram ignores refraction). The relative amount of B_S and B_T depend on the characteristics of the material 1 and the angle of incidence θ_1. The effect illustrated in Fig. 1 is present in even the most common inexpensive plastic sheet materials including, without limitation, polycarbonate, acrylic, PET, and PETG.

[0048] Fig. 2 is a schematic illustration, in longitudinal cross section, of an opaque material exhibiting both specular and diffuse reflection. A beam of light B_2 strikes the material 2 with an angle of incidence θ_2. A portion of the beam B_S is specularly reflected and a portion of the beam B_D is diffusely reflected. As above, the relative amount of B_S and B_D depend on the characteristics of the material 2 and the angle of incidence θ_2. The effect illustrated in Fig. 2 is present in varying degrees in a wide variety of inexpensive and commonly available materials including, without limitation, white vinyl tape, flooring tape, PVC, and other appliques.

[0049] Fig. 3 is a graph of reflectivity versus angle of incidence for an exemplary transparent material which exhibits specular reflection. As can be seen from Fig. 3, for shallow angles of incidence, where incident light is close to parallel with a material surface, Fresnel reflection can be very efficient. Fig. 3 shows reflectivity versus angle of incidence for a dielectric surface with an index of refraction of about 1.58.

[0050] Fig. 4 is a schematic view, in longitudinal cross section, of a light pipe according to a first example of the invention. A light pipe 4 includes a clear plastic conduit 6 having a relatively low index of refraction. To effectively and uniformly distribute the light through the light pipe, some light must be passed down the pipe and some light must be allowed to exit the light pipe. According to the invention, a material having both a specular reflection component and a diffuse reflection component is disposed along the length of the pipe. As shown in Fig. 4, a reflecting material 8 is disposed on an inside surface of the conduit 6. The material 8 provides both a specular reflection component and a diffuse reflection component. In application, a light source 10 provides a beam of light into the light pipe 4. The beam of light has a relatively small full beam angle of less than about 30°. For example, for plastics with an index of refraction of about 1.5, a beam of light with a relatively narrow full beam angle of less than about 15-20° is preferred. A lower beam angle of light yields fewer bounces for a given length and aspect ratio of light pipe, thereby improving light distribution efficiency.

[0051] A reflective end cap or mirror may be placed at the end of the light pipe 4 opposite the light source 10. Preferably the mirror is tilted at angle which improves the light distribution and / or efficiency (e.g. about +/- 10 degrees). Alternatively, the mirror may have a curved surface for redirecting light back into the light pipe. The

light pipe 4 may also be sealed with a clear plastic plate or lens at the end closest to the light source 10. The plate or lens may include an anti-reflective coating.

[0052] Fig. 5 is a schematic diagram of a beam of light striking the reflecting material 8. A beam of light 12 which strikes the material 8 produces a specular component 14 which remains at relatively shallow angles of incidence and is passed down the light pipe. Because the reflection occurs from the first surface, the light beam does not have to transit the material with each reflection, resulting in lower losses per bounce. The beam of light 12 striking the material 8 also produces a diffuse component 16 at relatively higher angles of incidence which exits the light pipe 4. Because the light makes only a few bounces inside the light pipe 4, and because relatively thin plastic sheets with low in-sheet losses may be utilized, the losses in the pipe material are low and the distribution of the light is highly efficient.

[0053] Advantageously, suitable light pipe materials are inexpensive and readily available. For example, many types of common adhesive tape have both a specular reflection component and a diffuse reflection component on their non-adhesive surface. The relative magnitudes of the respective components vary as a function of the angle of incidence. In other words, when the tape is viewed from directly above (i.e. a high angle of incidence) the tape appears to have a dull finish and when the tape is viewed from the side (i.e. a shallow angle of incidence) the tape appears to have a glossy finish. Exemplary tapes include 3M#471 made by the Minnesota Manufacturing and Mining Company and #6029T118 made by McMaster-Carr, both of which are common white vinyl tape. These particular tapes are considered illustrative and not limiting. Generally any highly white or reflective material with similar characteristics will work well.

[0054] Also advantageously, suitable conduit materials are inexpensive and readily available. For example, the conduit 6 may be constructed from 0.5 mm (0.020 inch) thick clear polycarbonate. Different grades of plastic may be utilized depending on the target environment for the light pipe (e.g. UV resistant materials may be desirable for outdoor use). Other suitable materials include PET, PETG, and acrylic. Such plastics may be ordered in various lengths and widths. The conduit 6 is formed, for example, by laying out a desired length of plastic having a width corresponding to a desired circumference of the pipe. The material 8 is applied to the plastic on a desired surface thereof. The plastic is then rolled to form a cylinder and the ends of the plastic may be taped together at the seam. The ends may abut or overlap. The seam may be sealed by other methods including gluing or ultrasonic welding. Alternatively, the seam need not be sealed at all if other means are provided for maintaining the light pipe structure. Other methods of forming the conduit will be apparent to those skilled in the art.

[0055] Suitable light sources include any high brightness light source capable of producing a beam of light with a desired beam angle. For example, a spotlight is typically capable of producing a relatively small beam angle. Another suitable source is the lamp described in PCT Publication No. WO 99/36940, entitled "High Frequency Inductive Lamp and Power Oscillator," together with suitable optics to produce the desired beam angle. Another suitable light source includes a microwave driven sulfur or selenium lamp of the type generally described in U.S. Patent No. 5,404,076 entitled "Lamp Including Sulfur." Preferably, such a lamp is configured with a reflective microwave cavity as shown in Fig. 14 of U.S. Patent No. 5,903,091 together with suitable optics for producing the desired beam angle. A

preferred microwave aperture lamp is described in co-pending application no. 60/133,885 entitled "High Brightness Microwave Lamp."

[0056] Fig. 6 is a schematic view, in longitudinal cross section, of a light pipe according a second example of the invention. According to the second example of the invention, a plurality of layers of plastic material are utilized to distribute light through a light pipe. A light source 20 provides a beam of light with a relatively narrow beam angle into one end of a light pipe 24. The light pipe 24 includes an inner pipe 26 and outer pipe 28. A reflecting material 30 is disposed on an inside surface of the outer pipe 28. The reflecting material 30 has both a specular and diffuse reflection component as described above. Preferably, the reflecting material 30 extends along substantially the entire length of the light pipe 24.

[0057] An air gap 32 is provided between the inner pipe 26 and the outer pipe 28. The purpose of the air gap is to provide a suitable air-to-pipe interface to improve confinement of the light within the light pipe (due to double glint reflection between the pipes) and to avoid loss of light which might occur if the inner pipe 26 contacted the outer pipe 28. Preferably, the air gap is about 1-2 mm wide, although the size of the gap is not critical. A suitable spacer element (not shown) is utilized to maintain the air gap along the length of the light pipe. For example, the air gap may be provided by a plurality of clear plastic rings positioned between the pipes and spaced along the length of the light pipe 24. Alternatively, the inner pipe 26 may be wound with nylon line or the like to provide the air gap. In another alternative, the plastic sheet may be formed with ribs or embossments to provide a suitable air gap.

[0058] Fig. 7 is a schematic view, in cross section, of the light pipe illustrated in Fig. 6 taken along line 7-7. As illustrated in Fig. 7, the inner and outer pipes 26, 28 are substantially concentric. The reflecting material 30 conforms to the inside

surface of the outer pipe 28 and covers some angular fraction of the inside surface of the pipe 28. The angular fraction of the reflecting material may be varied to provide a desired light output. A portion of the light striking the reflecting material 30 is scattered into beams which are not well contained by the Fresnel reflection effect. These beams are scattered from the reflecting material 30 in directions principally orthogonal to the plane of the surface of the tape. For example, as shown in Fig. 7, with the reflecting material placed in an upper semi-circle of the cross-section of the light pipe 24, the scattered light from the reflecting material 30 will be principally into directions described by the lower semicircle of the light pipe 24.

[0059] In general, the transmission capability of the light pipe according to the invention is proportional to the outer diameter of the light pipe. A larger diameter pipe provides less internal bounces of the light and the light leakage rate depends upon the number of bounces. With multiple layers of clear plastic boundaries (e.g. 2 or more concentric plastic pipes), the light pipe according to the invention distributes the light over a distance of greater than about 50 pipe diameters. For example, for a 38 cm (15 inch) diameter pipe this corresponds to more than 19 meters (60 feet) while maintaining high uniformity (better than about 25% over most of the pipe). Typically, a greater number of layers is provided closer to the light source and / or near the mirrored end cap (see Fig. 11). According to the invention, the uniformity and distribution of light along the light pipe is controlled by adjusting the number of layers, the length of each layer, and the finish of each side of each layer (i.e. diffuse or glossy).

[0060] Figs. 8-11 are schematic views of alternative structures for light pipes according to the second example of the invention. In each of Figs. 8-11, the number of layers varies along the distance of the pipe. By varying the number of concentric

plastic pipes as a function of distance down the pipe, the light pipe according to the invention controls the rate at which light is allowed to escape the light pipe. In Fig. 11, a section of diffusing material 34 is provided near both the light source and the mirrored end cap to reduce the appearance of a bright spot at either end of the light pipe.

[0061] According to another aspect of the invention, the desired reflecting properties may be achieved by applying a variety of materials to the surface of a plastic sheet such that the resulting structure has both specular and diffuse reflection components when viewed through the plastic sheet from the opposite face. Fig. 12 is a schematic diagram, in cross section, of an alternative construction of a light pipe according to the invention. A light pipe 44 includes a plurality of concentric conduits 46, 48. In Fig. 12, a reflecting material 50 is disposed on an outside surface of an outermost conduit 48. For example, the reflecting material 50 may comprise a white tape. Fig. 13 is a schematic diagram of a beam of light 52 striking the inside surface of the conduit 48. As can be seen in Fig. 13, the inside surface of the outermost conduit 48 provides the specular reflection component 54 for shallow angles of incidence and the material 50 on the outer surface provides the diffuse reflection component 56 resulting from the transmitted portion of the beam 52. Accordingly, under this aspect of the invention the material 50 need not provide a specular component itself. Exemplary alternatives for the reflecting material 50 include, for example, Tyvek® taped to the outermost conduit 48 or any other diffusely reflecting material suitably secured to the outside surface of the outermost conduit 48.

[0062] Fig. 14 is a diagram of a light output pattern for a light pipe according to the invention utilizing a plastic sheet having a gloss finish on both sides. A light

pipe 60 includes a plastic conduit 61 bearing a reflecting material 62 on an inside surface 63 thereof. The reflecting material 62 covers about 180° of the interior surface 63 of the conduit 61, thereby defining a light output window of about 180° on the opposite side of the pipe 60 with respect to the reflecting material 62. Both the inside surface 63 and an outside surface 64 of the conduit 61 have a gloss finish. Accordingly, light scattered by the reflecting material 62 exits the pipe 60 in a pattern approximated by the dashed line 65.

[0063] By utilizing a non-glossy finish for the outermost surface of the outermost plastic conduit, such as a matte or velvet finish commonly available, the light escaping from the pipe is further diffusely scattered by the non-glossy finished side of the plastic sheet. Fig. 15 is a diagram of a light output pattern for a light pipe according to the invention utilizing a plastic sheet having a gloss finish on its interior side and a diffuse finish on its exterior side. A light pipe 66 includes a plastic conduit 67 bearing a reflecting material 68 on an inside surface 69 thereof. The reflecting material 68 covers about 180° of the interior surface 69 of the conduit 67. The inside surface 68 has a glossy finish and provides specular reflection for passing shallow angle light down the pipe 66. An outside surface 70 of the conduit 66 has a non-glossy finish and further diffuses light exiting the pipe 66. Accordingly, light scattered by the reflecting material 68 exits the pipe 66 in a pattern approximated by the dashed line 71.

[0064] Where multiple concentric conduits are employed for transporting light down the light pipe, generally only the outer surface of the outermost conduit is desired to be a matte, velvet, or other diffusely scattering finish. An exception to this general rule may be applied in the regions of the light pipe closest to the light source and the mirrored end cap, such that those beams not within the angles that are

efficiently transported by the Fresnel reflection effect are more diffusely scattered, lessening the direct view glare for these beams (which otherwise would escape the light pipe in a concentrated spatial and angular cone). Notwithstanding the general rule, the present invention contemplates the use of glossy and / or diffuse surfaces for any of the plurality of layers as may be beneficial for any particular application.

[0065] Fig. 16 is a schematic diagram of the light output from yet another example of a light pipe according to the invention. A light pipe 72 is similar to the light pipe described in connection with Fig. 12, including the outer conduit 48 with reflecting material 50 disposed on an outer surface thereof. The light pipe 72 further includes an additional silvered or aluminized reflector 73 around approximately 270° of the outermost conduit 48 and a diffusing tape 74 over the output window defined by the reflector 73. As shown in Fig. 16, a relatively directional output approximated by the dashed line 75 is expected.

[0066] Fig. 17 shows an illustrative example of a hemispherical shaped light pipe with a flat bottom 76 made from diffusing material and a silvered / aluminized reflector 77 around the top. Figs. 18-20 show respective cross sectional views for alternative light pipe configurations according to the present invention.

[0067] Fig. 21 is a schematic view of a first plastic sheet in a preliminary stage of preparation for forming a light pipe according to the present invention. Fig. 22 is a schematic view of a second plastic sheet in a preliminary stage of preparation for forming a light pipe according to the present invention. Fig. 23 is a cross sectional view of a first preferred configuration for a light pipe according to the invention.

[0068] With reference to Figs. 21-23, an exemplary first configuration of the invention is constructed as follows. A 2.4 m (8 feet) section of light pipe 80 includes a pre-formed clear plastic rigid jacket 82 having an approximately 15 cm (6 inch)

outer diameter. An approximately 47 cm (18.4 inch) wide by 2.4 m (8 feet) long plastic polycarbonate sheet 84 (0.5 mm / 0.02 inch thick) having a gloss finish on one side and a matte finish on the other side is prepared with several slightly overlapping strips of white vinyl tape running lengthwise down the sheet to provide an approximately 18 cm (7 inch) wide strip 86 of reflecting material on each side of the gloss finish side of the sheet. This leaves an approximately 11 cm (4.8 inch) transparent strip 88 down the middle of the sheet 84. The sheet 84 is rolled with the tape 86 on the interior and held to a diameter of less than 15 cm (6 inch) and inserted in the rigid jacket 82. The sheet 84 is then released and unrolls against the outer jacket 82. The two strips 86 abut each other or overlap slightly to provide an approximately 270° reflecting surface and a 90° light transmissive window defined by the transparent strip 88.

[0069] Another plastic sheet 94 of approximately 46 cm (18.1 inch) wide by 2.4 m (8 feet) long plastic polycarbonate sheet (0.5 mm / 0.02 inch thick) having a gloss finish on both sides is prepared with strips of neoprene 96 across the width of the sheet 94 spaced every 45 cm (18 inch) or so. The neoprene 96 is approximately 1.5 mm (1/16th inch) thick and is glued to the sheet with translucent RTV 108 silicone. After drying, the sheet 94 is rolled with the neoprene 96 on the outside and held to a diameter of less than 15 cm (6 inch). The sheet 94 is then inserted in the pipe section 80 and released to unroll against the earlier inserted sheet 84. The neoprene 96 provides an air gap between the two layers of plastic sheet 84, 94.

<u>Performance Data for the first configuration</u>

[0070] Three such sections 80 are assembled and connected together to form a 24 foot long light pipe. The rigid jackets 82 abut and are taped at the seams. A small length of the inner layers 84, 94 may extend beyond the ends of the rigid

jacket 82 and may be interleaved with the next section's inner layers. The light pipe is suspended from a ceiling and illuminated with a Cyberlight® spotlight, commercially available from High End Systems, Austin, Texas. The spotlight provides approximately 7000 - 8500 lumens of light in a collimated beam which may be adjusted from between about 15° to 28° full beam angle. A reflective end cap is mounted on the end of the light pipe opposite the spotlight. The reflective portion of the end cap is tilted about 10° from vertical.

[0071] Exemplary normalized performance data for an approximately 15° full beam angle light source as measured from about 30 inches away from the pipe is as follows:

Distance (pipe diameters)	Light Output Normalized Lux
0.83	0.42
3.83	0.81
6.83	0.92
10	0.94
12.83	1
15.83	0.98
19.67	0.94
22.67	0.92
25.67	0.92
28.67	0.92
31.67	0.94
35.5	0.94
38.5	0.93
41.5	0.98
44.5	0.99
47.5	0.78

Table 1

[0072] Figs. 25 and 26 are graphs comparing light output of the light pipe of the above-described configuration with a conventional TIR light pipe. The conventional TIR light pipe is a 25 cm (10 inch) diameter pipe utilizing OLF for light distribution. The conventional TIR light pipe was illuminated by a commercially available LightDrive™ 1000 light source, available from Fusion Lighting, Inc.,

Rockville, Maryland. The light source is adapted with a reflector for directing light into the light pipe. It should be noted that the conventional TIR system just described is considered to be a good performer in terms of light distribution and uniformity. However, as shown in Figs. 25 and 26, the light pipe of the present invention distributes light even more uniformly over a greater proportionate length of pipe. Also, because the beam angle is relatively narrow, the light output is less intense in the section of light pipe immediately adjacent the source. With the conventional TIR system, as can be seen from Fig. 25, a significant amount of light output tends to be concentrated near the source, which can cause an unwanted glare at that end of the light pipe.

[0073] Fig. 24 is a cross sectional view of a second preferred configuration for a light pipe according to the invention. With reference to Figs. 21-22 and 24, an exemplary second configuration of the invention is constructed as follows. A six foot section of light pipe 100 includes a rolled outer sleeve 102 having an approximately 15 cm (6 inch) outer diameter. An approximately 47 cm (18.4 inch) wide by 1.8m (6 feet) long plastic polycarbonate sheet 84 (0.5 mm / 0.02 inch thick) having a gloss finish on one side and a matte finish on the other side is prepared with a strip of highly reflective Mylar running lengthwise down the sheet to provide an approximately 18 cm (7 inch) wide strip 86 of reflecting material on each side of the matte finish side of the sheet. For example, several overlapping strips of transparent double sided tape may be utilized to secure the Mylar to the sheet 84. This leaves an approximately 11 cm (4.8 inch) transparent strip 88 down the middle of the sheet 84. One side of the sheet 84 is inserted in a channel 105a of an extruded mounting device 107 with the strip 86 on the outside. The sheet 84 is then taped or otherwise suitably secured to one side of the mounting device. The sheet 84 is then rolled with

the strip 86 on the exterior and the free edge of the sheet 84 is inserted in the open channel 105b. The sheet 84 is then taped or otherwise suitably secured to the other side of the mounting device 107, thereby forming the outer sleeve 102. The two strips 86 provide an approximately 270° reflecting surface and a 90° light transmissive window defined by the transparent strip 88. Depending on the material used for the mounting device, a strip of reflective material 104 may be disposed on an interior surface of the mounting device 107 to provide desired light reflecting characteristics (e.g. some combination of diffuse and / or specular reflection).

[0074] Another plastic sheet 94 of approximately 46 cm (18.1 inch) wide by 1.8 m (6 feet) long plastic polycarbonate sheet (0.5 mm / 0.02 inch thick) having a gloss finish on one side and a matte finish on the other side is prepared with 3 strips of 3M transparent foam tape 96 across the width of the sheet on the matte finish side. One strip is approximately centered and the other two strips are spaced about 15 cm (6 inch) from each end. The tape 96 is approximately 1.5 mm (1/16th inch) thick. The sheet 94 is rolled with the tape 96 on the outside and held to a diameter of less than 15 cm (6 inch). For example, one or both sides of the rolled sheet 94 may be secured with masking tape. The sheet 94 is then inserted in the pipe section 100 and released (e.g. the masking tape is removed) to unroll against the outer sleeve 102. The tape 96 provides an air gap between the two layers of plastic sheet 84, 94.

[0075] Five such sections 100 are assembled and connected together to form a 30 foot long light pipe. Two additional layers of diffusing material, one about 120 cm (4 feet) long and the other about 90 cm (3 feet) long, are positioned in the first section near the light source to reduce the appearance of a bright spot. The outer sleeves 102 abut and may be taped or otherwise coupled together at the seams. A

small length of the inner layers 84, 94 may extend beyond the ends of the outer sleeves 102 and may be interleaved with the next section's inner layers. The light pipe is suspended from a ceiling and illuminated with a high intensity metal halide lamp disposed in a parabolic reflector. A suitable lamp is commercially available from Osram / Sylvania of Danvers, MA as model no. VIP R 400/32. The lamp provides approximately 20,000 lumens of light in a focused beam having an approximately 12° full beam angle. A reflective end cap is mounted on the end of the light pipe opposite the spotlight. A concave reflector is positioned in the end cap to reduce the appearance of a bright spot at the end of the light pipe distal to the source.

<u>Mounting and coupling mechanisms</u>

[0076] Those skilled in the art will appreciate that any of a number of conventional mounting and coupling mechanisms may be utilized to suspend or otherwise mount the light pipe of the present invention proximate to a ceiling or in an otherwise desirable location within an area to be illuminated. Likewise, many conventional coupling devices may be used to join sections of light pipe together.

[0077] Figs. 27 and 28 are perspective views of mounting devices according to an aspect of the invention which cooperate to provide up to three layers of conduit without the need for spacer elements. With reference to Fig. 27, a first mounting device 120 is made from extruded plastic, typically with a length corresponding to a desired length of a light pipe section. The mounting device 120 includes a post portion 122 which is substantially perpendicular to opposed fins 124a and 124b. The fins 124a and 124b may be curved to a radius corresponding to a desired radius of the conduit.

[0078] With reference to Fig. 28, a second mounting device 130 is also made from extruded plastic, typically with a length corresponding to a desired length of a light pipe section. A body portion 132 of the mounting device 130 defines a channel 134 which is adapted to receive the post 122 of the first mounting device 120. The body 130 further defines a plurality of mounting holes, 135a, 135b, 135c, and 135d which may be utilized to secure the mounting device 130 directly to the ceiling (e.g. with bolts through holes 135a, b) or to a U-shaped track (e.g. with pins through holes 135c, d). The holes 135a, b may be internally countersunk to provide a clearance for the bolt head and avoid interference with the post 122. Likewise, the holes 135c, d should be positioned to avoid interference between the pin and the post 122. The mounting device 130 further includes a plurality of fins 136a, 136b and 138a, 138b which are curved to respective radii corresponding to desired radii of the conduits.

[0079] In application, the first mounting device 120 is utilized to provide one layer of conduit. The conduit is formed from a plastic sheet having a length corresponding to the length of the mounting device 120 and a desired width chosen to provide a desired overall circumference of the conduit (taken together with the fins 124a, b). One of the long edges of the sheet is secured to one fin 124a or 124b of the mounting device 120. For example, the edge may be secured by taping, gluing, ultrasonic welding, or other conventional means. The sheet is then rolled and the other edge is secured to the other fin.

[0080] Similarly, the mounting device 130 may be utilized to provide one or two layers of conduits. A first layer may be secured to the fins 136a, b, taking care not to cover the channel 134. For example, the sheet may be glued to the interior surface 136c of the fins 136a, b. Alternatively, the sheet may be secured in the

channel 136d formed between the two sets of fins. A second layer may be secured to the outer surface of the fins 138a, b.

[0081] Advantageously, the fins in each of the first and second mounting devices 120, 130 provide up to three layers of conduit and eliminate or reduce the need for additional spacer elements between the layers. If additional layers are desired, they may be prepared with spacer elements as otherwise described herein and unrolled against the conduit supported by the first mounting device 120.

[0082] Fig. 29 is a schematic view of a coupling device 140 according to the present invention. Fig. 30 is a cross sectional view of the coupling device 140 taken along line 30-30 in Fig. 29. The coupling device 140 is generally configured as a plastic ring with a pair of opposed channels 142a and 142b disposed around the circumference of the ring and parallel to a longitudinal axis of the light pipe. In application, an outer most layer of a light pipe section is inserted in the channel 142a or 142b and secured thereto by taping, gluing, ultrasonic welding, or other conventional means. Advantageously, the coupling device 140 helps the light pipe to holds its shape. To join light pipe sections together, a mating end of the next light pipe section is inserted in and secured to the open channel. When used together with mounting devices, such as those illustrated herein, the outermost conduit sections are configured to extended slightly beyond the ends of the mounting devices. Alternatively, the coupling device 140 may be configured as a semi-circular ring with an angular section removed which corresponds to the angular section occupied by the mounting device.

[0083] Fig. 31 is a cross sectional view of an end cap 160 according to the invention. The end cap 160 defines a channel 162 around its circumference and parallel to the longitudinal axis of the light pipe. The channel 162 is adapted to

receive a layer (e.g. the outermost layer) of the light pipe. An internal surface 164 of the end cap is preferably highly reflective and configured to redirect light which strikes the end cap back down the light pipe. Preferably, the surface 164 is tilted or shaped to improve the light distribution and or efficiency of the light pipe. For example, the end cap may include a mirror which is tilted about 10° toward the diffusing material to reflect the light back down the pipe and scatter the redirected light out of the light pipe. The mirror may be integral with the end cap 160 or may be a separate piece.

[0084] Fig. 32 is a cross sectional view of a second end cap 170 according to another aspect of the invention. The end cap 170 includes a mirror 172 with a curved surface 174. Preferably, the curved surface is configured to improve the light distribution and / or efficiency of the light pipe. For example, if a particular region of the light pipe is insufficiently illuminated, the curved surface 174 may be configured to focus the light striking the end plate at the diffusing material in the vicinity of the area requiring additional light output. The mirror 172 may be integral with the end cap 170 or may be a separate piece.

<u>Small scale light pipe</u>

[0085] A further advantage of the present light pipe is that very small diameter pipes may be made utilizing the principles of the invention. Prismatic film cannot be curled to very small diameters. An advantage of the present invention is that the material utilized can be either extruded at very small diameters or curled to very small diameters.

[0086] A light pipe which is approximately the same size as a typical florescent bulb is constructed as follows. Two cylindrical tubes are made from extruded plastic and cut to length of about 1.2 meters (4 feet). One tube has an

outer diameter which is slightly less than the inner diameter of the other tube. For example, the outer tube may comprise extruded Lexan™ having an outer diameter of 38 mm (1.5 inch) and a thickness of about 2-3 mm (1/8 inch). The inner tube may comprise extruded Lexan™ having an outer diameter of 31 mm (1.25 inch) with a thickness of 2-3 mm (1/8 inch). As an alternative to the extruded tubes, suitably thin plastic sheet may be rolled to form the light conduits.

[0087] The smaller diameter tube is inserted in the larger diameter tube and the tubes are separated by an air gap via suitable spacer means. For example, relatively thick (e.g. 0.5 - 1.0 mm) foam tape may be used at two or more points along the inner tube. Alternatively, an end cap may be provided with channels to receive each tube and position the tubes coaxially and in a non-contact configuration without spacers.

[0088] The outer tube is provided with a glossy interior surface and a diffuse finish (e.g. matte or velvet) exterior surface. The inner tube is provided with glossy interior and exterior surfaces. Highly reflective Mylar™ is disposed on one half (i.e. 180°) of the exterior surface of the outer tube and secured thereto with transparent double-sided tape or other suitable means.

[0089] The small scale light pipe is illuminated, for example, with the lamp described in section 4.4.2 of PCT Publication WO 99/36940 together with suitable optics for providing a tight beam angle of light. For example, suitable optics are shown in Figs. 33 and 34. Fig. 33 is a schematic view of a lens system suitable for use with the small scale light pipe of the present invention. Fig. 34 is a cross sectional view of the lens system taken along line 34-34 in Fig. 33. A lens system 200 includes a lens holder 202 housing a first lens 204, held in place by a retaining ring 206, and second and third lenses 208, 210 which are secured by a retaining ring

212. An exemplary first lens 204 is a 12 mm coated plano-convex lens which is commercially available from Edmund Industrial Optics, Barrington, New Jersey, USA, under part no. J45-303. Exemplary second and third lenses 208, 210 are both 45 mm coated plano convex lenses which are commercially available from Edmund Industrial Optics, Barrington, New Jersey, USA, under part nos. J45-150 and J32-895, respectively. The lens system functions to collect and focus the approximately 140° full beam angle of light from the aperture of the lamp to an approximately 22° full beam angle of light into the small scale light pipe. The second and third lens pair may be alternatively replaced with a single double convex lens. Those skilled in the art will appreciate that a wide variety of optical arrangements may be utilized to provide the desired tight beam angle of light.

Hybrid lighting

[0090] According to another aspect of the present invention, the light source for any of the light pipes of the present invention may be the sun. The sun, as seen from the Earth, is a 7° light source. Accordingly, the light pipes of the present invention may be beneficially utilized with sunlight, artificial light, or the combination of the two in a hybrid lighting system.

[0091] There has thus been described a simple, low cost, and efficient light pipe which may be constructed with readily available tapes and plastics using simple techniques. The light pipe according to the invention is applicable over a wide range of markets and scale sizes not previously contemplated for conventional TIR light pipe or other light tube applications.

[0092] The foregoing configurations of the present invention should be considered as illustrative only. Numerous variations will occur to those skilled in the art. For example, while the foregoing examples utilize primarily curved cross

sections of light pipe, this is only one example of a feasible cross section and other cross sectional shapes may be advantageous in other applications. A rectangular shape may be advantageous, for instance, in applications that retrofit into conventional drop ceilings with metal grid latticework, such as those designed to accept standard 2x2 or 2x4 florescent light fixtures. The shape of the bottom surface, along with its finish, may also be adapted for controlling beam divergence. The scope and spirit of the inventions is set forth in the appended claims.

CLAIMS

What is claimed is:

1. A light pipe comprising:

a conduit configured to receive light at one end and to distribute the light along its length, the conduit comprising a combination of specular and diffuse reflecting surfaces arranged to pass a portion of the light down the light pipe primarily with specular reflection and to emit a portion of the light out of the light pipe primarily with diffuse reflection, and wherein the reflecting surfaces are substantially parallel to a longitudinal axis of the light pipe.

2. The light pipe of claim 1, wherein the conduit comprises a clear plastic tube with an interior surface which provides specular reflection and an opaque material disposed along the length of the tube and covering a portion of the perimeter of the tube, wherein the opaque material provides diffuse reflection.

3. The light pipe of claim 2, wherein the opaque material is disposed on an interior surface of the tube and provides a combination of specular reflection for shallow beam angles of light and diffuse reflection for higher beam angles of light.

4. The light pipe of claim 2, wherein the opaque material is disposed on an exterior surface of the tube, and wherein the tube material and the opaque material together provide a combination of specular reflection for shallow beam angles of light and diffuse reflection for higher beam angles of light.

5. The light pipe of claim 1, wherein the conduit comprises an extruded plastic tube.

6. The light pipe of claim 1, wherein the conduit comprises plastic sheet material shaped to form a tube.

7. A light pipe comprising:

a plurality of conduits configured to receive light at one end and distribute the light along the length of the light pipe, the conduits being offset from each other by respective gaps and respectively comprising a combination of specular and diffuse reflecting surfaces arranged to pass a portion of the light down the light pipe primarily with specular reflection and to emit a portion of the light out of the light pipe primarily with diffuse reflection.

8. The light pipe of claim 7, wherein the number of conduits varies along the length of the light pipe.

9. The light pipe of claim 7, wherein the length of at least one of the conduits is different from the length of another of the conduits.

10. The light pipe of claim 7, wherein each of the conduits comprises either an extruded plastic tube or plastic sheet material shaped to form a tube.

11. The light pipe of claim 7, wherein each of the conduits except an outermost conduit comprises clear plastic having a gloss finish on both its interior and exterior surfaces.

12. The light pipe of claim 11, wherein the outermost conduit comprises clear plastic having a gloss finish on its interior surface and a diffuse finish on its exterior surface.

13. The light pipe of claim 12, further comprising an opaque material disposed along the length of the outermost conduit and covering a portion of the perimeter of the outermost conduit.

14. The light pipe of claim 13, wherein the opaque material is disposed on an interior surface of the outermost conduit and provides a combination of specular reflection for shallow beam angles of light and diffuse reflection for higher beam angles of light.

15. The light pipe of claim 13, wherein the opaque material is disposed on an exterior surface of the outermost conduit, and wherein the tube material and the opaque material together provide a combination of specular reflection for shallow beam angles of light and diffuse reflection for higher beam angles of light.

16. A light distribution system, comprising:

a light source providing a beam of light having a full beam angle of less than 30 degrees; and

a light pipe configured to receive the beam of light from the light source at one end and distribute the light along the length of the light pipe, the light pipe comprising a combination of specular and diffuse reflecting surfaces arranged to pass a portion of the light down the light pipe primarily with specular reflection and to emit a portion of the light out of the light pipe primarily with diffuse reflection.

17. The light distribution system of claim 16, wherein the light source provides a beam of light having a full beam angle of less than 20 degrees.

18. The light distribution system of claim 16, wherein the light source comprises sunlight.

19. The light distribution system of claim 16, further comprising:

an end cap covering an end of the light pipe distal to the light source, the end cap having a reflective surface positioned and shaped to redirect light back down the light pipe.

20. The light distribution system of claim 16, wherein the light pipe comprises first and second substantially concentric conduits, the distribution system further comprising:

a first mounting device adapted to support the first conduit; and

a second mounting device adapted to support the second conduit and adapted to receive and support the first mounting device and first conduit within the second conduit.

21. The light distribution system of claim 20, wherein the first and second mounting devices hold the first and second conduits in a non-contact relationship.

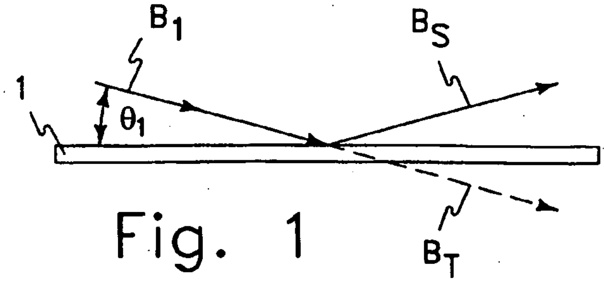

Fig. 1

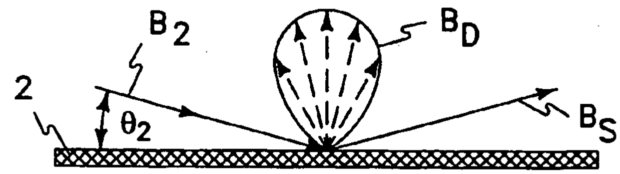

Fig. 2

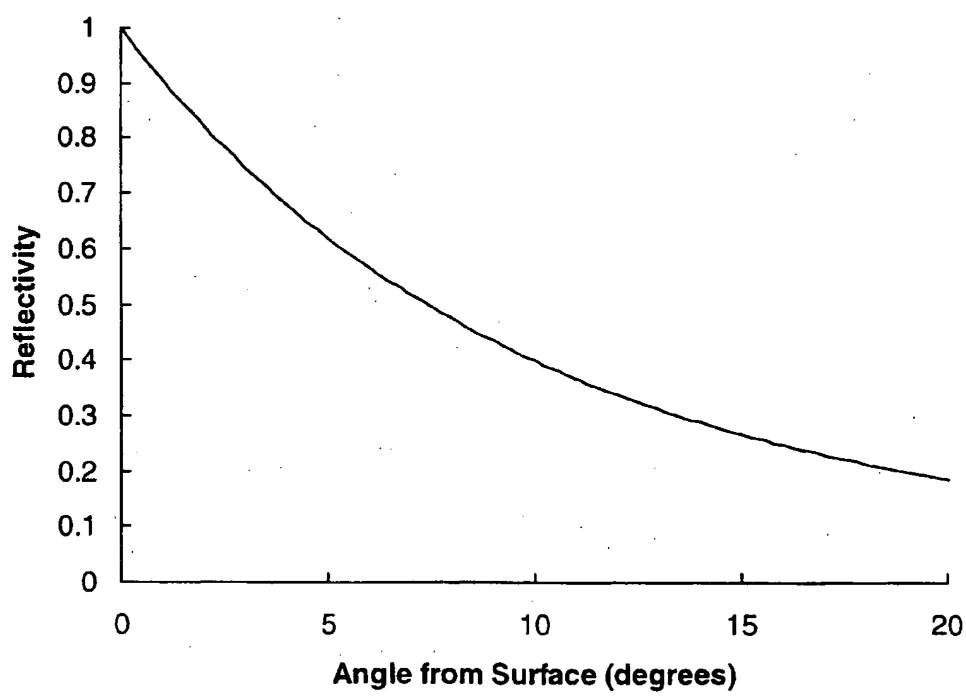

Fig. 3

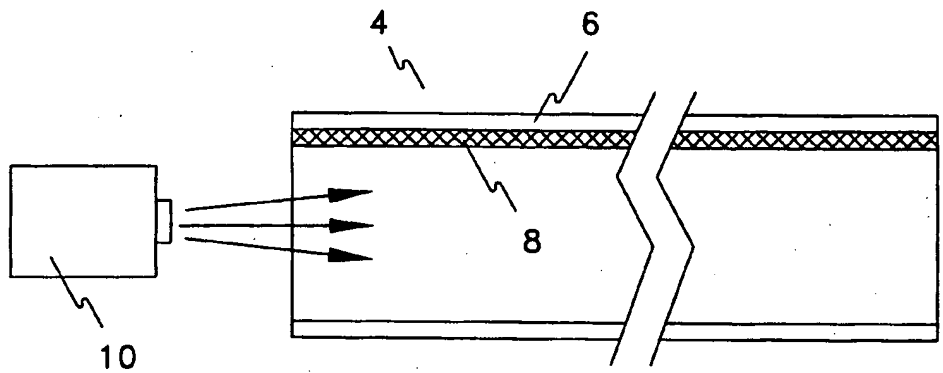

Fig. 4

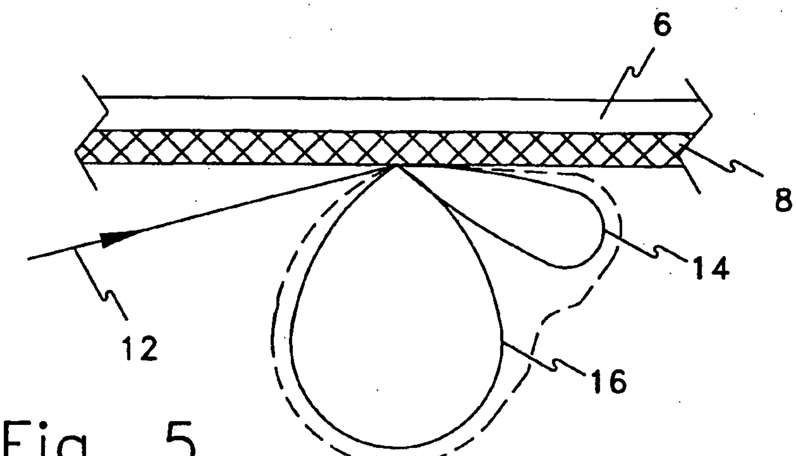

Fig. 5

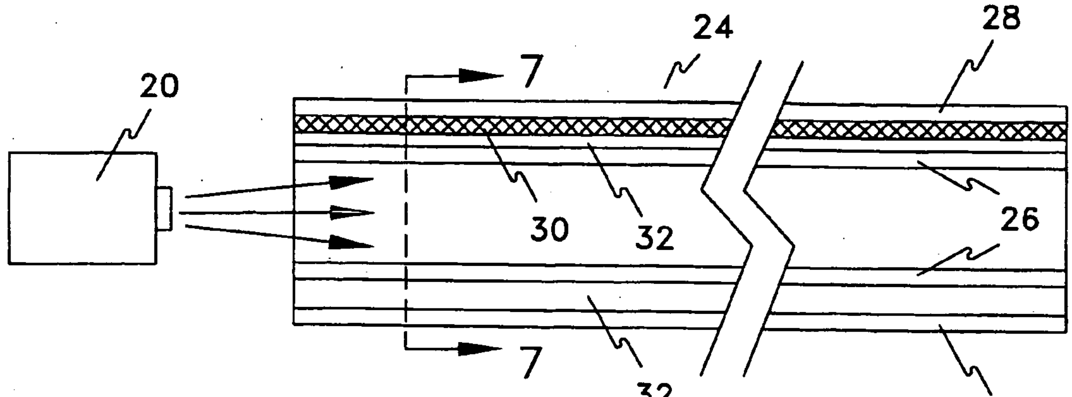

Fig. 6

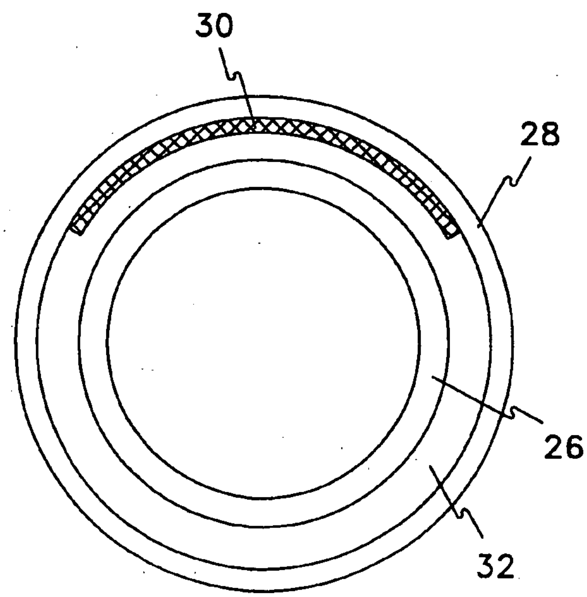

Fig. 7

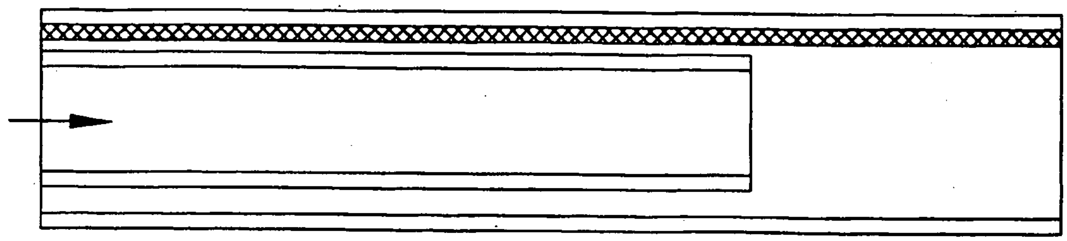

Fig. 8

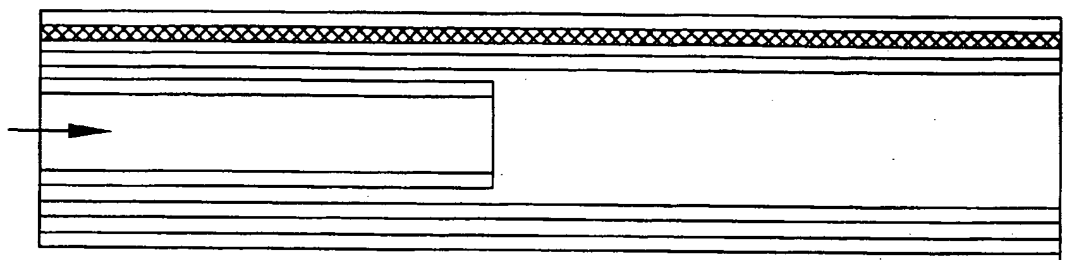

Fig. 9

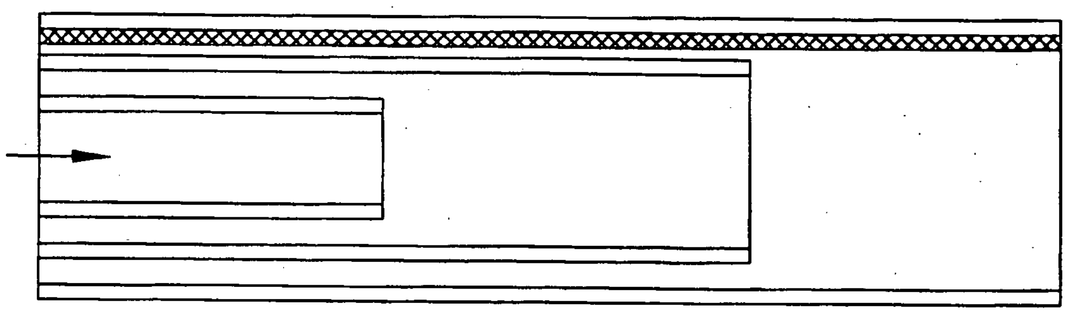

Fig. 10

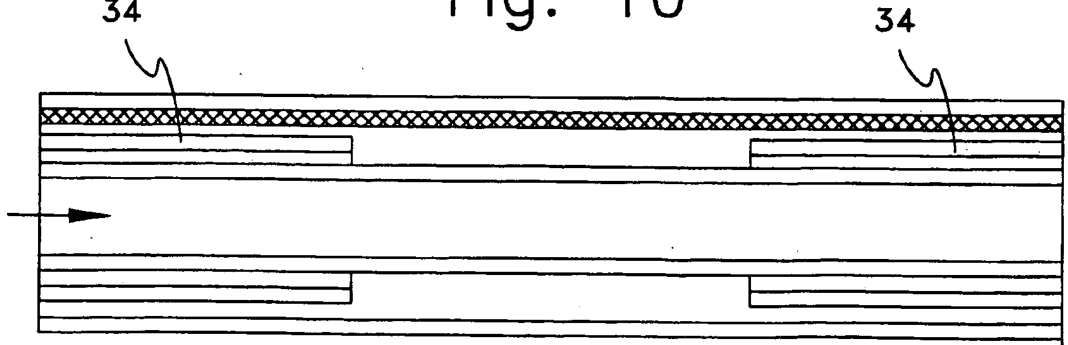

Fig. 11

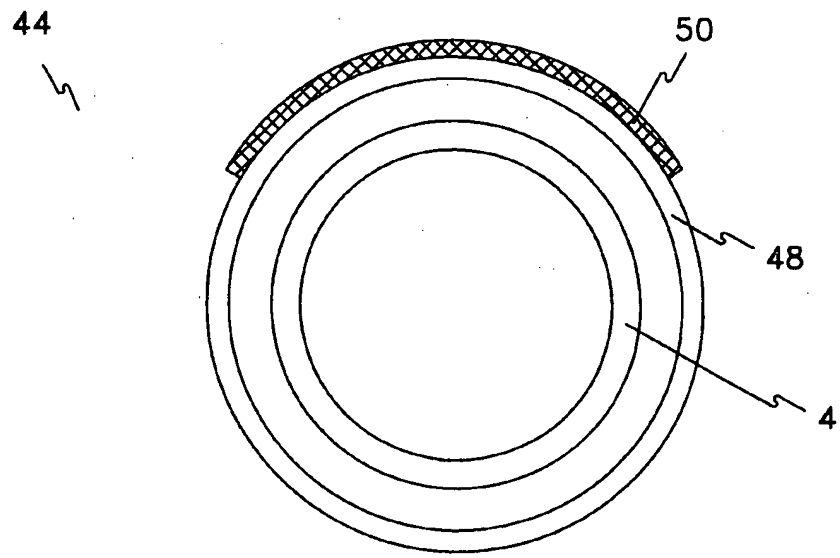

Fig. 12

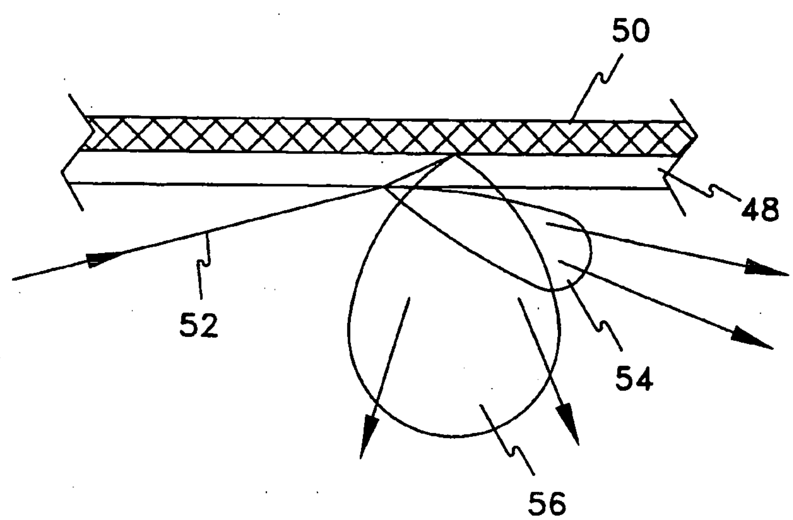

Fig. 13

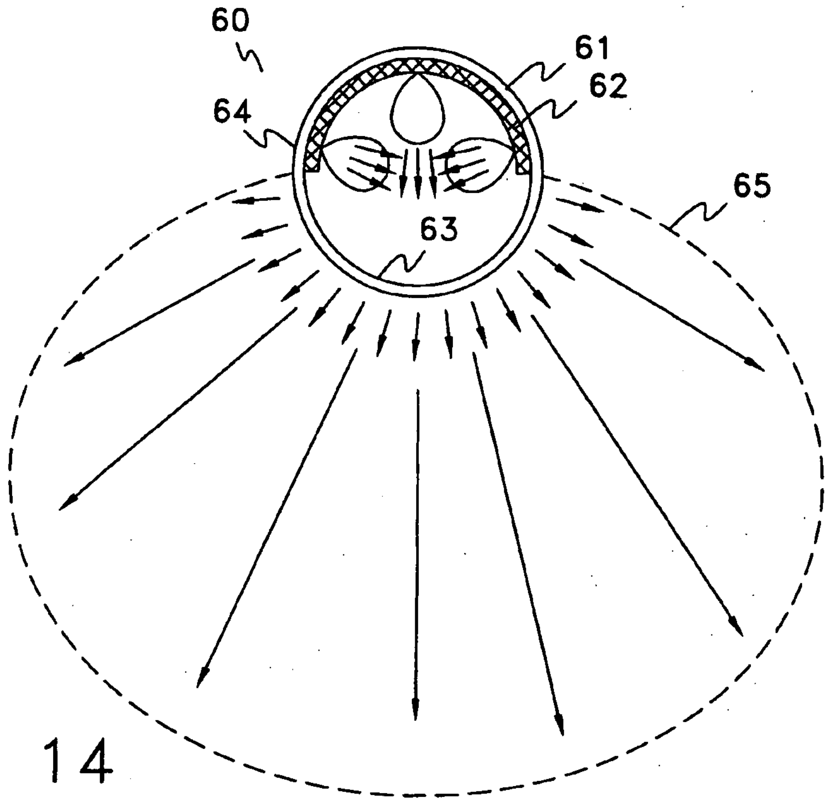

Fig. 14

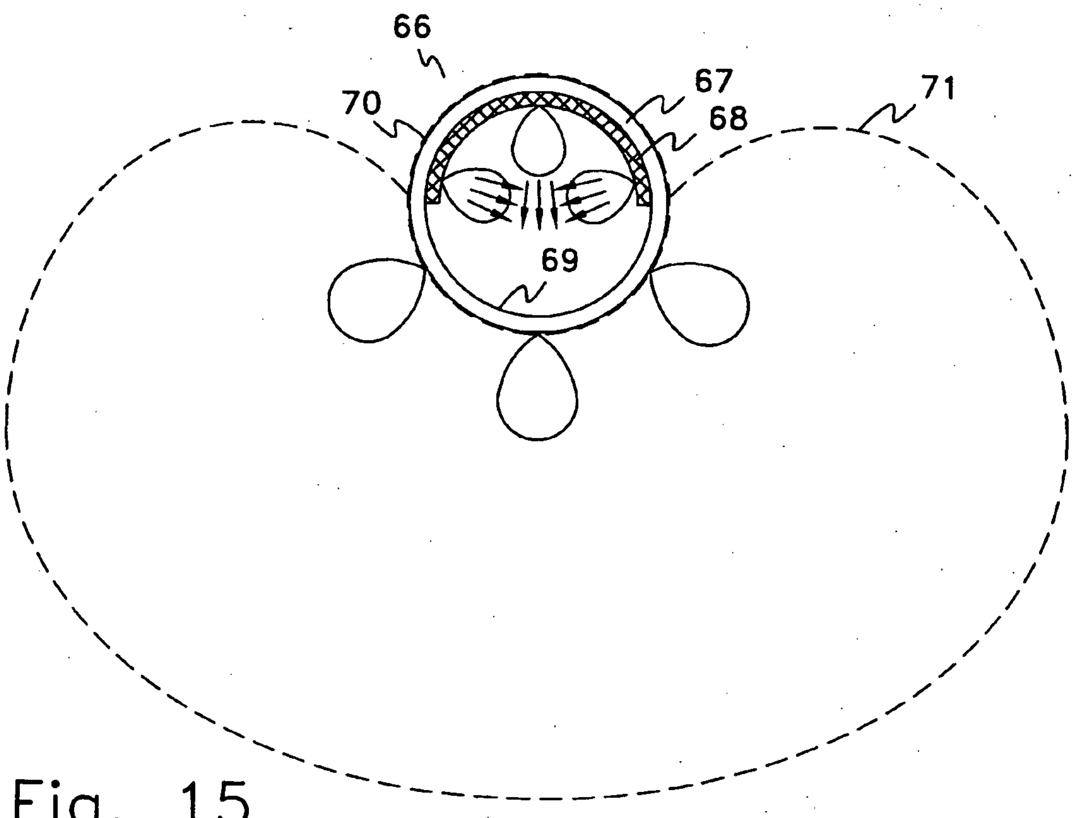

Fig. 15

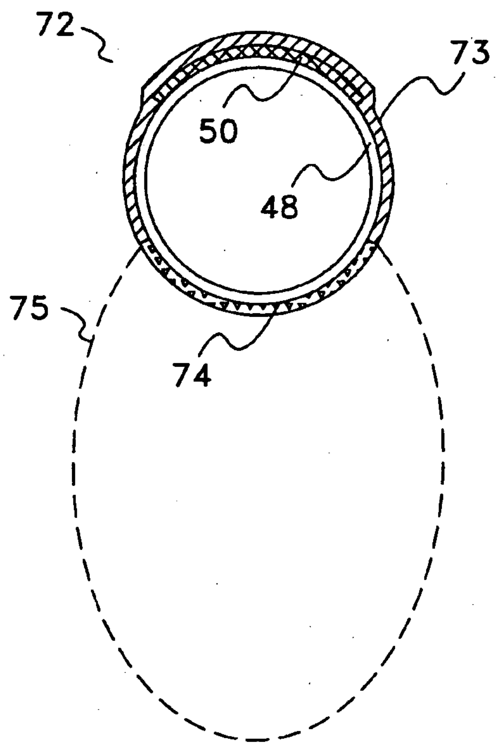

Fig. 16

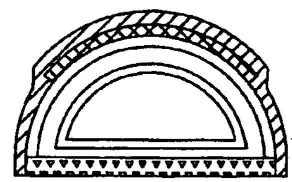

Fig. 17

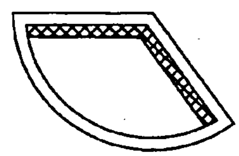

Fig. 18

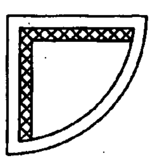

Fig. 19

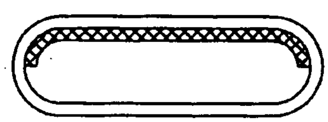

Fig. 20

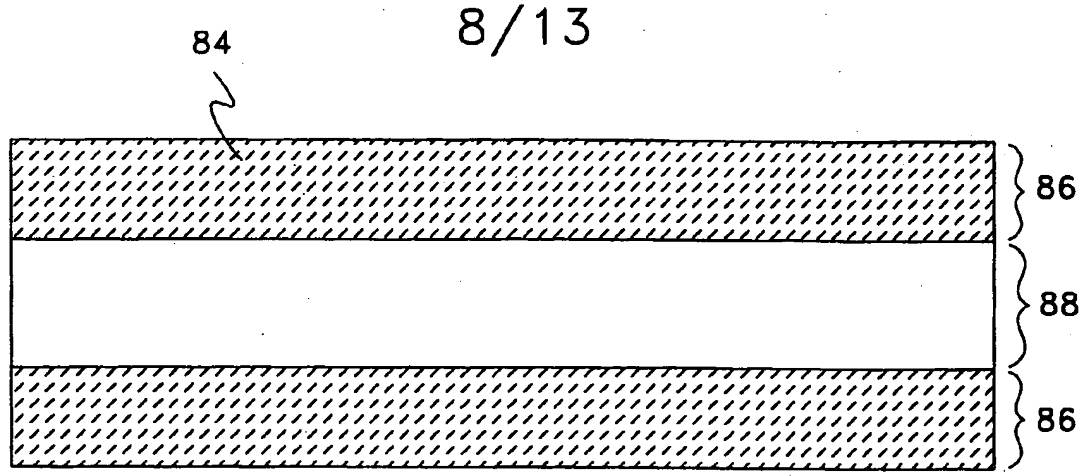

Fig. 21

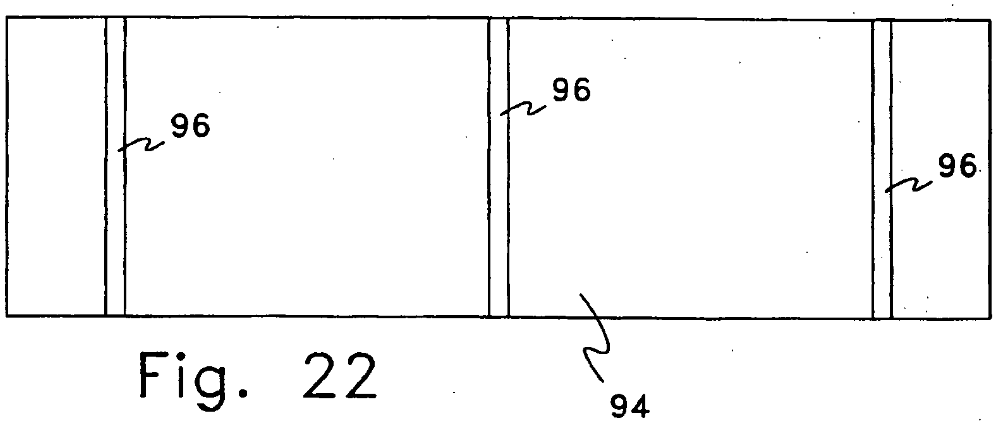

Fig. 22

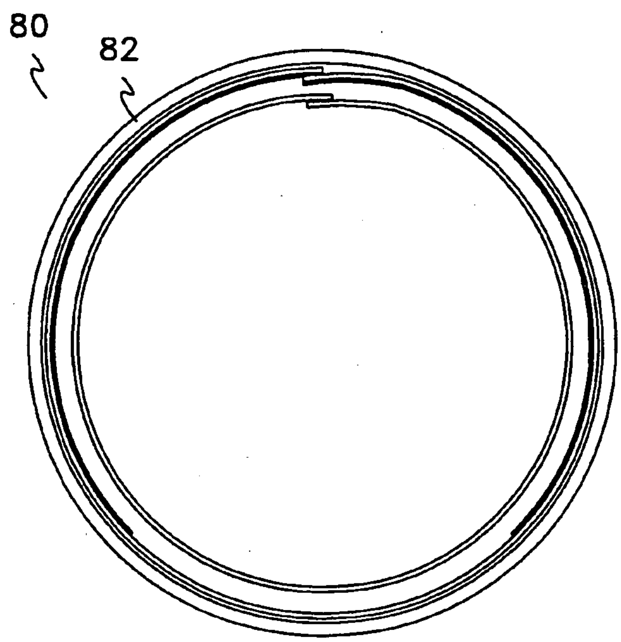

Fig. 23

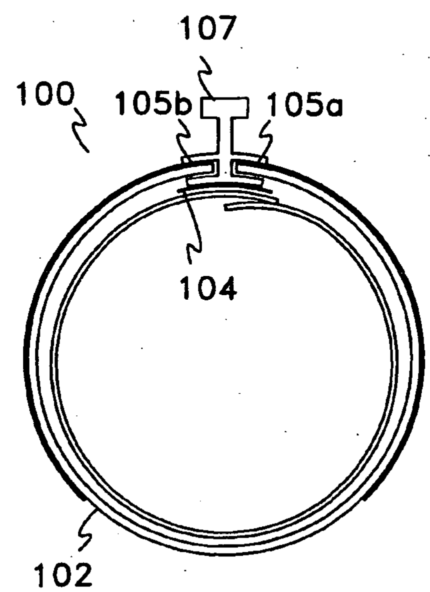

Fig. 24

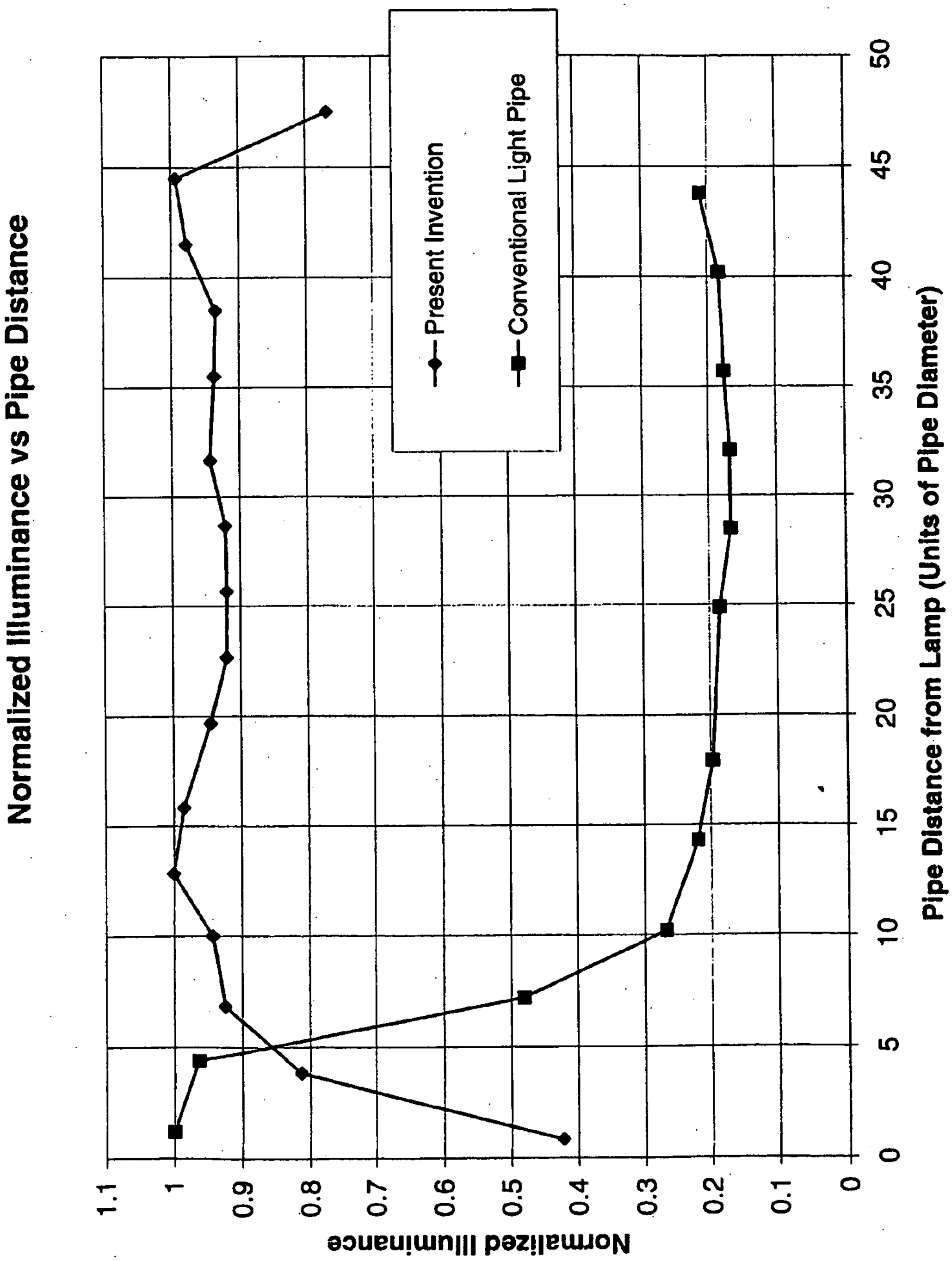
Normalized Illuminance vs Pipe Distance
Present Invention
Conventional Light Pipe
Normalized Illuminance
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Pipe Distance from Lamp (Units of Pipe Diameter)
0
5
10
15
20
25
30
35
40
45
50

Fig. 25

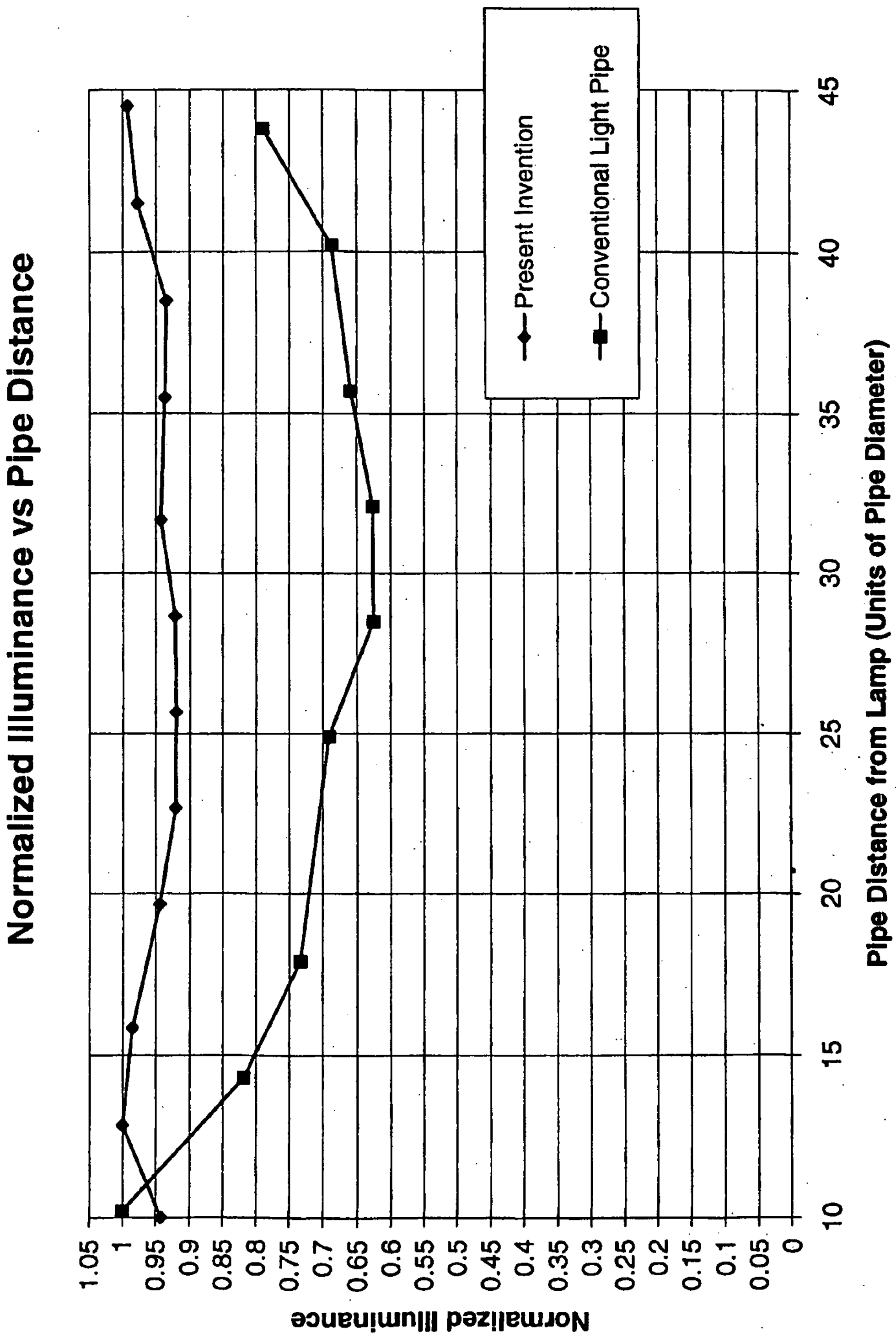
Normalized Illuminance vs Pipe Distance
Normalized Illuminance
Pipe Distance from Lamp (Units of Pipe Diameter)
Present Invention
Conventional Light Pipe
1.05
1
0.95
0.9
0.85
0.8
0.75
0.7
0.65
0.6
0.55
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
10
15
20
25
30
35
40
45

Fig. 26

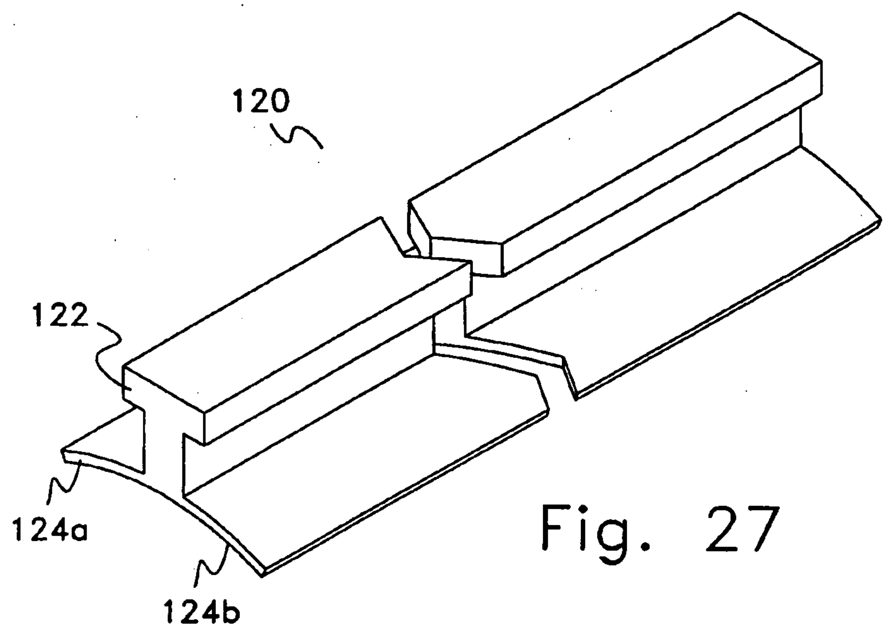
120
122
124a
124b

Fig. 27

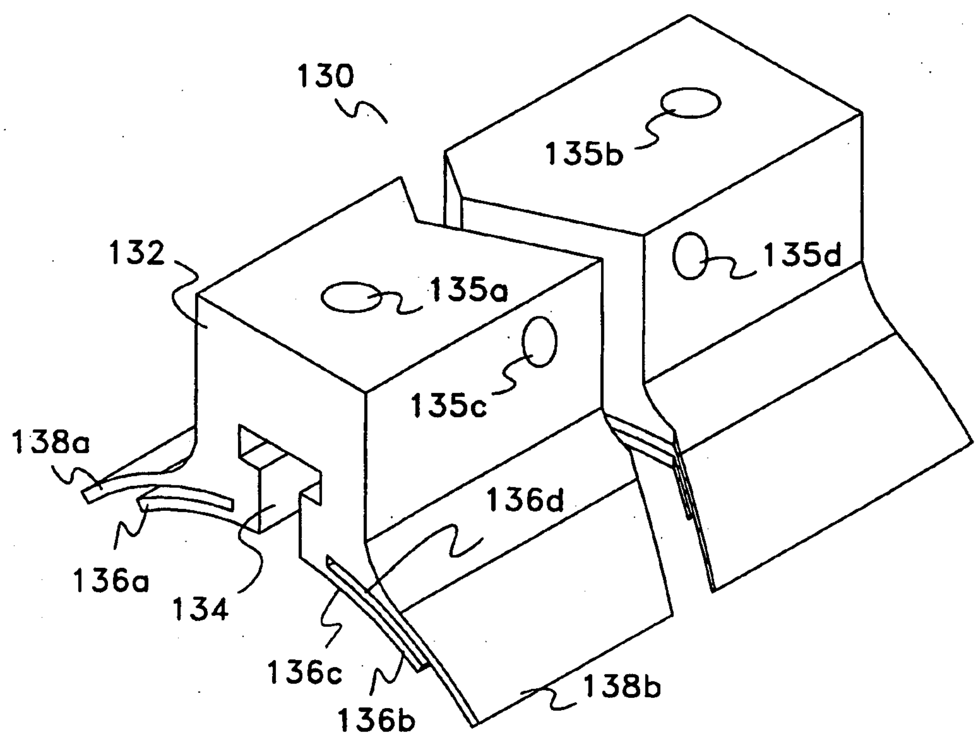
130
135b
132
135d
135a
135c
138a
136d
136a
134
136c
136b
138b

Fig. 28

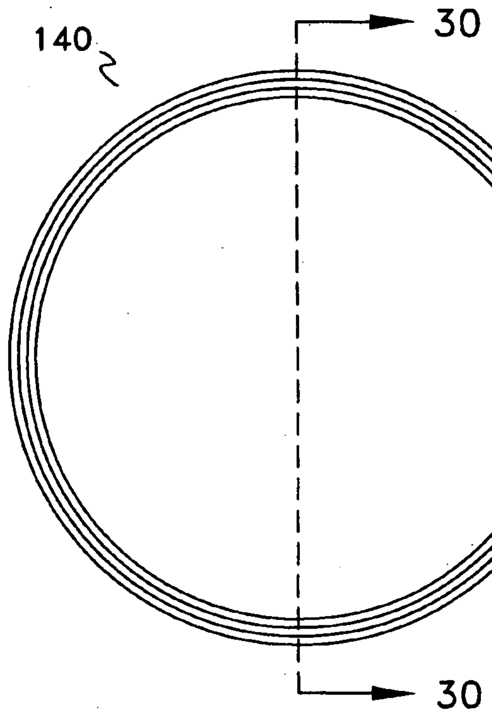

Fig. 29

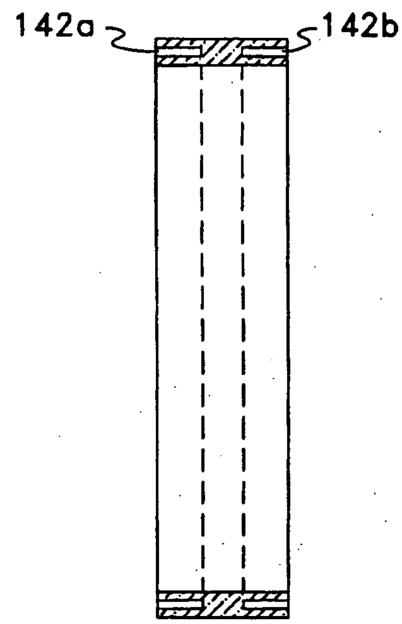

Fig. 30

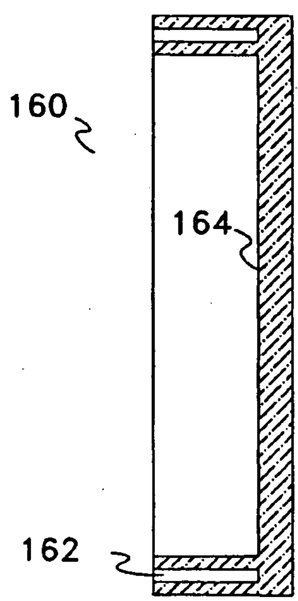

Fig. 31

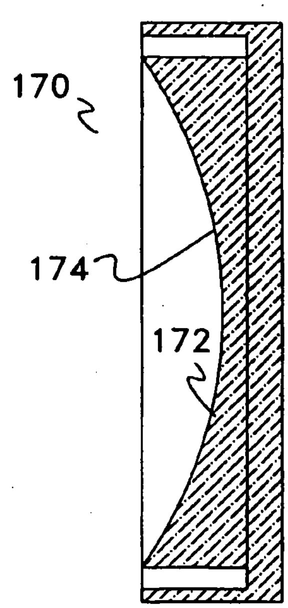

Fig. 32

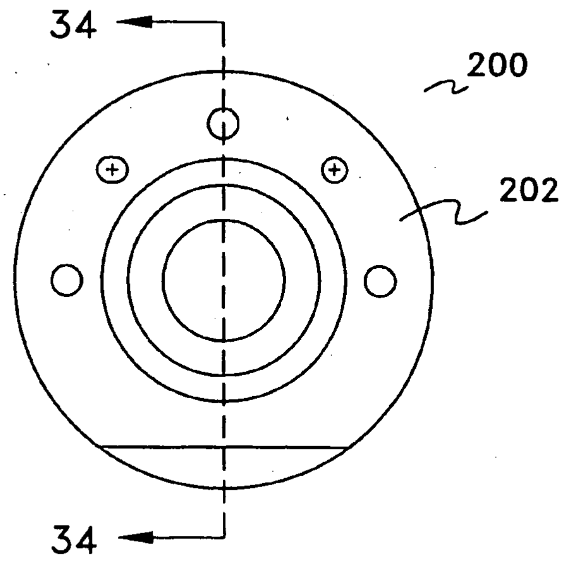

Fig. 33

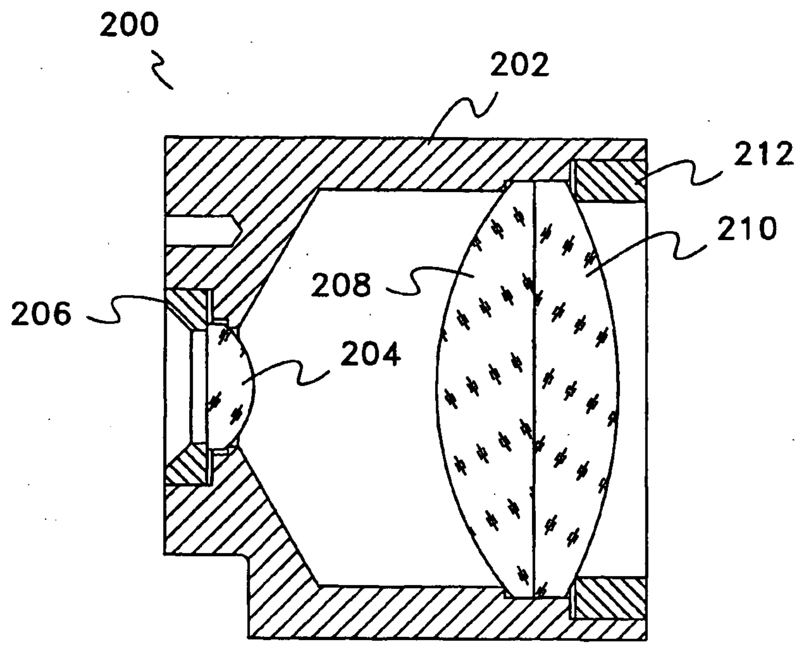

Fig. 34

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US00/00494

A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) :G02B 6/00
US CL :385/133, 901; 362/559; 430/363
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 385/133, 901, 146, 147; 362/559, 300, 350; 430/363, 376

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

NONE

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

USPTO APS LIGHT ADJ PIPE$1; CONDUIT$1 SAME DISTRIBUTE SAME LENGTH;
SPECULAR ADJ REFLECTION; DIFFUSE ADJ REFLECTION

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X --- A	US 4,260,220 A (WHITEHEAD) 07 April 1981 (07-04-1981), see figure 11.	1 --- 2-21
X --- A	US 4,906,070 A (COBB, JR.) 06 March 1990 (06-03-1990), see figure 6.	1 --- 2-21

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
10 APRIL 2000	21 APR 2000

Name and mailing address of the ISA/US	Authorized officer
Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231	PHAN T. H. PALMER
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